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CROSS-COUNTRY SPEED AND DRIVER VIBRATIONAL ENVIRONMENT OF THE M60 MAIN BATTLE TANK

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HUMAN ENGINEERING LABORATORIES

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ABSTRACT

This study investigated the g environment encountered by M60 tank drivers. It was conducted in two phases. In Phase I, the subjects drove an M60 tank over standard courses at constant speed. This phase examined the repeatability of measuring g loads when different drivers were subjected to the same environment. In Phase II, the subjects drove an M60 tank at maximum speed over two types of cross-country courses. This phase established a correlation between speed and g loads and determined the maximum g load the drivers would accept.

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CROSS-COUNTRY SPEED AND DRIVER VIBRATIONAL ENVIRONMENT OF THE M60 MAIN BATTLE TANK

INTRODUCTION

Cross-country speed is an important part of combat-vehicle mobility. Current developmental efforts are directed toward increasing cross-country speed by improving the vehicle's riding qualities. This implies some relationship between vibrational environment (g load) and vehicle speed. The Human Engineering Laboratories are working toward a description of this relationship.

The long-range objective is to describe how the environment limits all crew functions (driving, gunnery, commanding, etc.) within any combat vehicle. Ultimately, this will require measuring crew environments and how crews perform in a variety of vehicles traveling over many types of terrain. The present study, however, considers only the driver of an M60 tank.

This study was conducted in two phases. In Phase I, the subjects drove an M60 tank over standard courses at constant speed. This phase examined the repeatability of measuring g loads when different drivers were subjected to the same environment. In Phase II, subjects were told to drive an M60 tank at "maximum" speed over two types of cross-country courses. This phase established a correlation between speed and g loads and determined the maximum g load the drivers would accept.

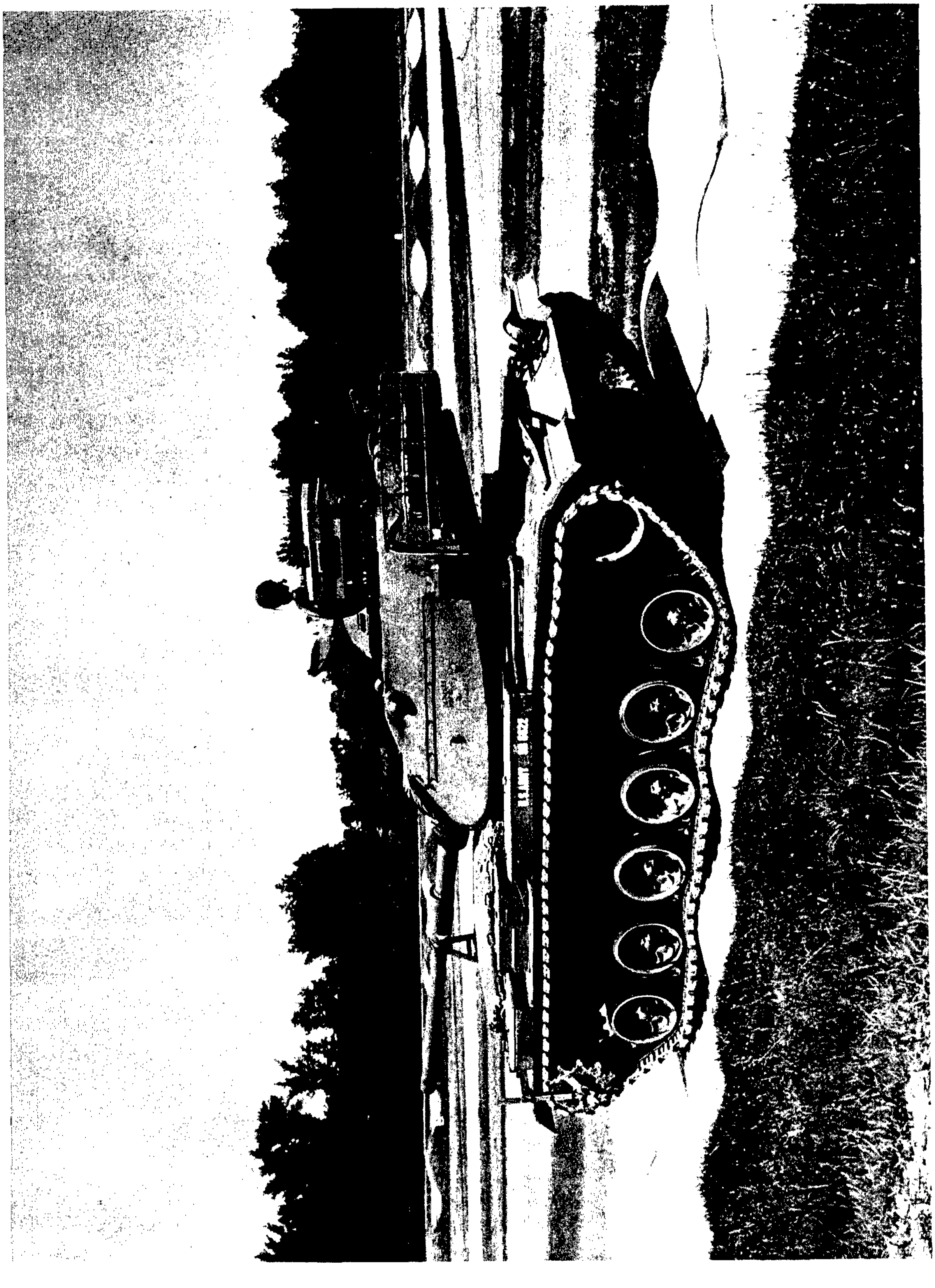

Fig. 1. SIX-INCH WASHBOARD COURSE

METHOD AND PROCEDURE

Subjects

The subjects (Ss) in this study were nine soldiers. Seven of the Ss were from the 16th Armor Group, Fort Knox, Ky., and two were from the military complement assigned to the Human Engineering Laboratories, Aberdeen Proving Ground, Md. All of the Ss from the 16th Armor Group had a Military Occupational Specialty (MOS) of 131 (tank-crew member), with from two months' to ten years' experience in that MOS. Of the two Ss selected from the Human Engineering Laboratories, one's MOS was 131, with ten years' experience in MOS, and the other's MOS was 409.34 (mechanical engineer assistant), with two months' experience in driving tanks. The Ss' physical characteristics (weight, height, and build) ranged from the 5th percentile to the 95th percentile (Table 14B).

The Ss, although trained to operate the vehicle, had little training on the test courses used; thus the terrain was relatively unknown to them when the study started. The Ss were briefed on the specific requirements of each phase of the testing.

Vehicle

The vehicle tested was an M60A1 main battle tank. Prior to this study, new tracks were installed and the entire suspension system was checked over for defects. At the start of the actual testing, the vehicle had logged approximately 2500 miles and was in good running condition.

Courses

The courses used in this study were of two general types: (a) Phase I -- standard courses, which produce repetitive g loadings on the vehicle; and (b) Phase II -- cross-country tank courses, which produce random g loadings on the vehicle. The standard courses (Figs. 1 and 2) were a six-inch washboard course and a 6- to 12-inch staggered-bump course. These courses are assembled from cast concrete sections. The cross-country courses consisted of various types of cross-country terrain selected from Courses #2 and #3 of the Perryman test area (Fig. 3). They were chosen for this phase because they represented generally the combination of terrain features encountered on most cross-country runs: namely, bumps that vary randomly in amplitude and frequency of occurrence.

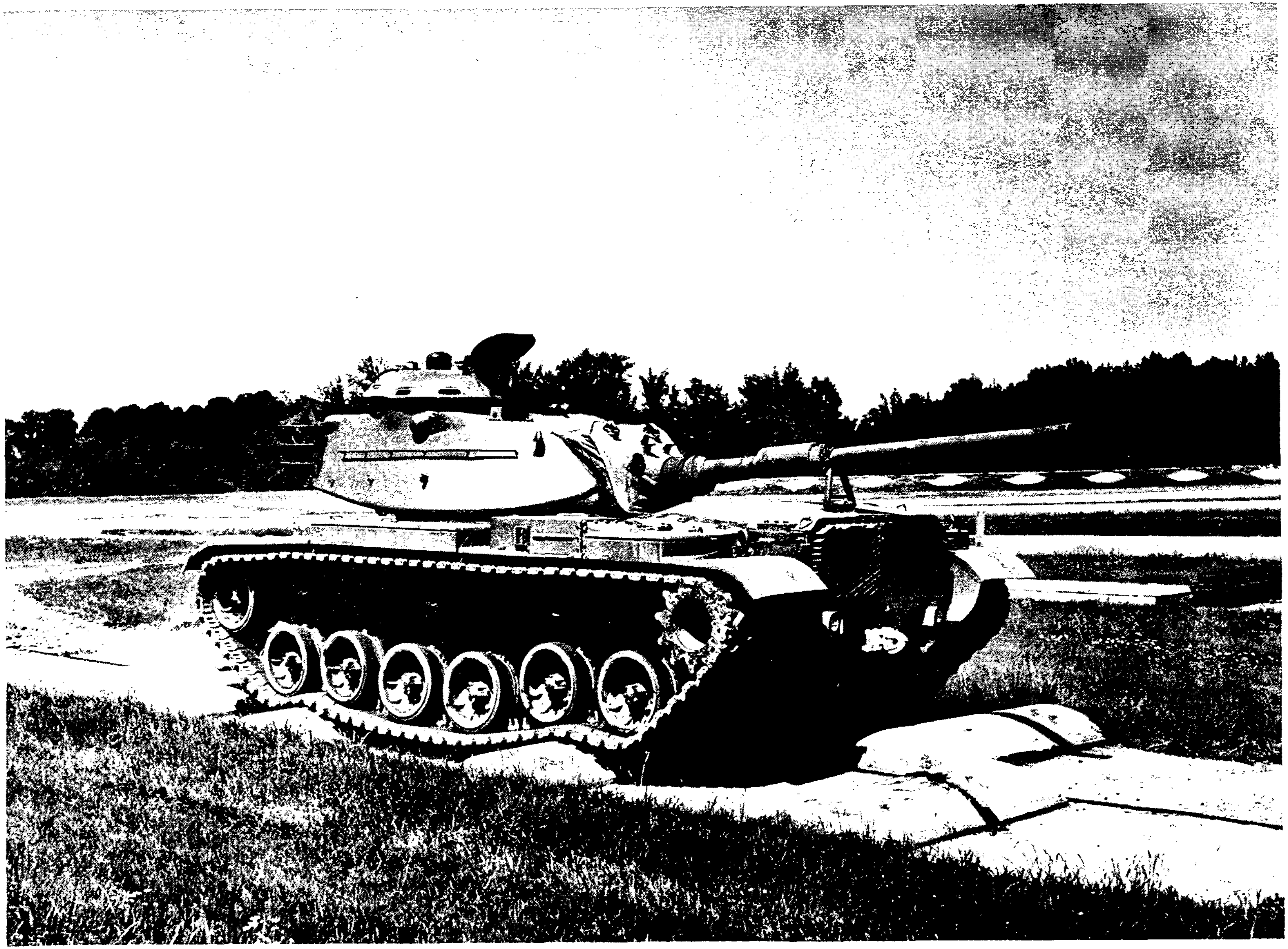

Fig. 2. SIX-TO-TWELVE-INCH STAGGERED-BUMP COURSE

Fig. 3. PERRYMAN TEST AREA

Fig. 4. ACCELEROMETERS ATTACHED TO VEST

The section of Course #2 was the 1.7-mile loop, which is made up of random combinations of smooth and rough portions. The section of Course #3 was the 1.5-mile straight portion, made up of varying sine-wave-type bumps which range from one- to three-foot peak-to-valley excursions occurring at 20- to 60-foot intervals. Soil conditions included dust, dirt, mud, and shallow water.

Instrumentation

The instrumentation equipment consisted of three Consolidated Electrodynamics Corporation (CEC) strain-gauge accelerometers with a range of ± 5 g, three Statham strain-gauge accelerometers with a range of ± 25 g, a CEC DC bridge balance, six Dana solid-state DC amplifiers, an Ampex 14-channel magnetic tape recorder operating at 1 7/8 in./sec., and a self-contained DC and AC power supply. A master power-control panel and a calibration panel were constructed to aid in operating the instrumentation. The calibration panel was designed to allow a zero and a +2 g calibration to be placed on the recording tape.

The three CEC accelerometers were attached to a vest the driver wore (Fig. 4), and three Statham accelerometers were mounted underneath the driver's seat. The accelerometer outputs were fed through the bridge balance and amplifiers to the recorder. The output of the accelerometers mounted on the driver's seat was fed through a filter with an attenuation of 6 dB per octave above 10 cycles per second (cps). This filter removed frequencies above 10 cps from the recorded data, since they do not cause the human body to accelerate. The vehicle speeds and throttle positions were also recorded. Road speed was measured by a Meriam pulse generator attached to the tank's drive sprocket, and throttle position was measured by a potentiometer connected to the throttle linkage.

DATA COLLECTION

Phase I

The first phase examined the repeatability of g-load measurements when different drivers were subjected to the same vibrational conditions. The conditions were reproduced by having each S traverse the standard courses at constant speeds: 16 mph for the six-inch washboard course, and 5 mph for the 6- to 12-inch staggered-bump course.

This phase was to include two repetitions of the course, one on each of two days. These results would have shown the repeatability of g-load measurements within Ss; but, because of recording problems, only the second series of runs could be analyzed.

Phase II

The second phase had two purposes: (a) establishing a correlation between cross-country speeds and driver g loads; and (b) determining the maximum g-load levels drivers will accept while driving cross-country.

In this phase the course was not traversed at constant speeds, but at speeds the Ss themselves determined. Before the tests began, the Ss were told that this phase was set up to measure their tolerance to g loads and that they should travel the courses as fast as they felt possible. They were told to consider only their own well-being, not that of the vehicle or instrumentation.

The cross-country phase was designed to include two identical series of tests on each course. In the first series, five of the Ss were to use the open-hatch driving position, and four the closed-hatch position. The Ss were to switch driving positions in the second series of tests. Each subject was to use both positions, to reduce the effects of the S's familiarity with the details of the course and also to provide a comparison of performance at the two driving positions.

However, there were many suspension-system difficulties during the actual data collection (Appendix A). Road-wheel bearings and arms failed on Course #2 about every fourth run (approximately every seven miles). Therefore, testing on this course was limited to one run per driver in the open-hatch position.

There were also difficulties with the instrumentation on the cross-country courses. Many runs produced incomplete data; therefore the Course #3 runs that did not yield complete data from all three driver channels were repeated.

DATA REDUCTION

Data consisted of an electrical signal (analogous to g level) which oscillated about zero. The amplitudes and frequency content of these oscillations were continuous variables. Data of this type can be reduced in three basic ways:

a. Root-Mean-Square signal levels (RMS g) -- This is a convenient reduction method, and it provides a simple statistic for further analysis. For these reasons, most analyses in this report use RMS g.

b. Amplitude Distribution -- This gives the percentage of time that the g level exceeded given levels. The amplitude distributions were determined for Phase II data, but unique distributions are not handy for further analysis; therefore, none was made.

c. Fourier Analysis for Frequency Content (Spectral Density or Power Spectra) -- This analysis finds the RMS g level as a function of frequencies. It is a very time-consuming analysis, because the tapes must be played through completely for each frequency to get precise results. Although no power spectra are shown in this report, several small samples of data were reduced in this manner. These samples showed that nearly all the energy was below 10 cps.

The g-environment data collected during this study were recorded on magnetic tapes. These tapes were then played through two analyzer circuits simultaneously -- to obtain RMS g values and amplitude distributions. (Appendix C gives a detailed description of data-reduction procedures and equipment.)

The data reduction planned for both phases of this study was to include finding the RMS g values and the amplitude distributions. However, checking the recorded data on an oscilloscope revealed that, on the standard courses, most of the g loadings were well below the 2-g level. These small loadings, together with the short duration of the run (30-60 seconds), would have required major modifications in the amplitude-analyzer circuit. Therefore amplitude distributions were not obtained for this phase.

RESULTS

In discussing the results of these tests, the values computed from raw data must be qualified in two ways: (a) the measured results may deviate from the actual environment by as much as 10 percent because of the recording and reduction techniques, and (b) a 10° accelerometer tilt produces two percent gain error and 20 percent cross-talk. The vertical measurements are not greatly affected by these problems, but the horizontal measurements would contain a 0.2-$\underline{g}$ error from 20 percent cross-talk due to normal gravity.

Phase I

The results of the first phase, although incomplete due to excessive recording noise and intermittent channels, show that all $\underline{S}$s' bodies responded to $\underline{g}$ environments, especially vertical $\underline{g}$s, in about the same way (Tables 1B and 2B). It was evident that the results of the second phase would not have to be adjusted to isolate variations in body characteristics.

Phase II

The results of phase II indicate that $\underline{S}$s had widely differing RMS $\underline{g}$ and amplitude distributions. Also, average vehicle speeds varied greatly from one course to another (Tables 3B through 12B). To examine these differences, the results were analyzed further. RMS $\underline{g}$ and vehicle speed were correlated for each channel, to find out whether differing average speeds could account for variations in RMS $\underline{g}$ level that $\underline{S}$s experienced. Product-moment coefficients ($\underline{r}$) were computed for each channel, as shown in Appendix B (Tables 3B, 4B, and 5B). This analysis showed that the average correlation, calculated using the $\underline{Z}$ transformation, was low ($\underline{r}$ = 0.60) for both transverse and longitudinal channels. However, the vertical-channel correlations for both vehicle and driver were high ($\underline{r}$ = 0.95).

The correlation between individual $\underline{g}$ levels in the amplitude distribution and vehicle speed was computed for the driver-vertical channel only (Tables 6B and 8B). Since these coefficients indicate about the same correlation as with RMS $\underline{g}$, RMS $\underline{g}$ was selected as the variable to be formally related to speed.

To describe the relationship between RMS $\underline{g}$ and average vehicle speed, the data were converted to logarithmic forms. The linear-regression technique (RMS $\underline{g}$ on speed) was then used to obtain mathematical expressions describing the relationship for each course. Separate expressions were computed for open-hatch and closed-hatch driving positions for Course #3. The similarity of these expressions for the driver indicates that this type of analysis is reliable. The computed expressions are as follows:

Driver - Vertical

Where V = average vehicle speed:

Course #2 - RMS $\underline{g} = 2.05 \times 10^{-4} (V)^{2.8}$

Course #3 Combined - RMS $\underline{g} = 28.8 \times 10^{-4} (V)^{2.0}$

Open Hatch - RMS $\underline{g} = 22.0 \times 10^{-4} (V)^{2.1}$

Closed Hatch - RMS $\underline{g} = 22.5 \times 10^{-4} (V)^{2.1}$

Vehicle - Vertical

Where V = average vehicle speed:

Course #2 - RMS $\underline{g} = .166 \times 10^{-4} (V)^{2.8}$

Course #3 Combined - RMS $\underline{g} = 17.5 \times 10^{-4} (V)^{2.2}$

Open Hatch - RMS $\underline{g} = 86.3 \times 10^{-4} (V)^{1.6}$

Closed Hatch - RMS $\underline{g} = 8.1 \times 10^{-4} (V)^{2.6}$

The Course #2 expression and the combined Course #3 expression were plotted with their corresponding data points (Figs. 5 through 8). These plots show that the two courses differed for both the driver and the vehicle data channels.

With an M60 tank, speed and environment were measured on Perryman Courses #2 and #3 and related in a fairly straightforward manner. Unfortunately, the maximum tolerable $\underline{g}$ level could not be determined clearly for several reasons:

a. Vehicles with higher power-to-weight ratios may have been able to go faster, thereby raising the average $\underline{g}$ level.

b. Different types of terrain may affect the results.

c. Different trial durations may produce different results.

d. Different positions (crew stations) in the vehicle may have different environments (Appendix D).

e. Even under the limited conditions of this test, the results were highly variable.

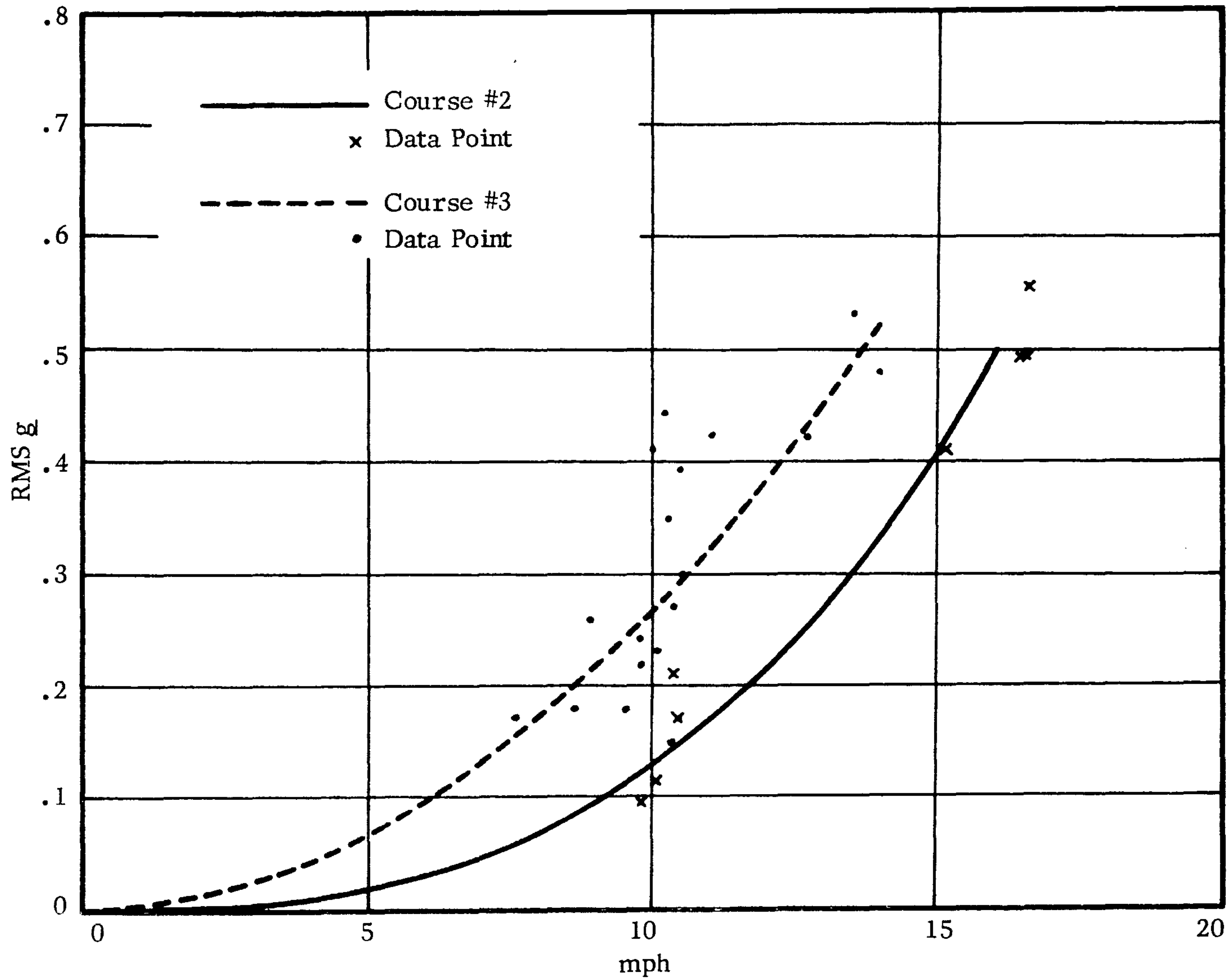

Fig. 5. CROSS-COUNTRY RESULTS: DRIVER, VERTICAL
(RMS g vs. average vehicle speed)

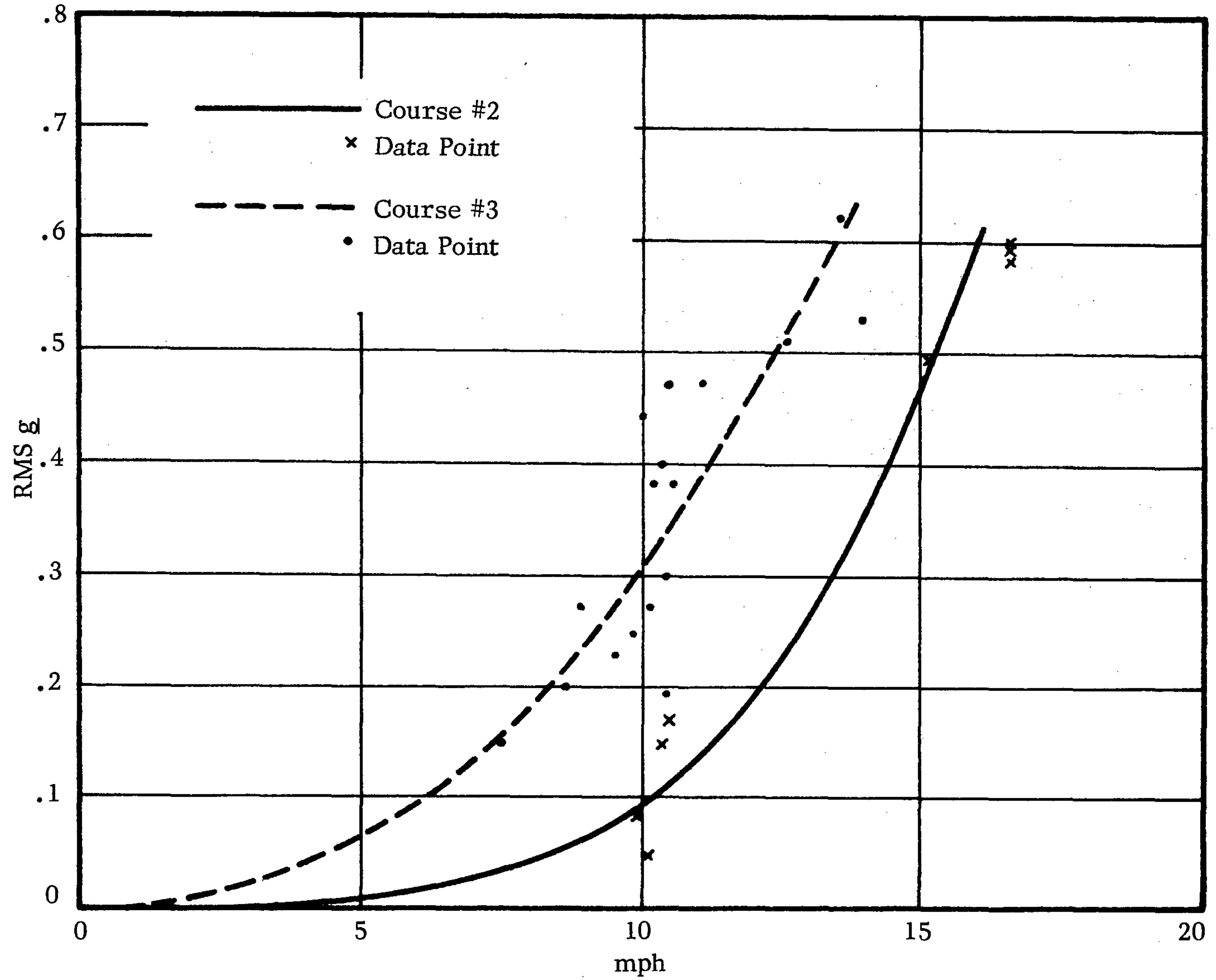

Fig. 6. CROSS-COUNTRY RESULTS: VEHICLE, VERTICAL
(RMS g vs. average vehicle speed)

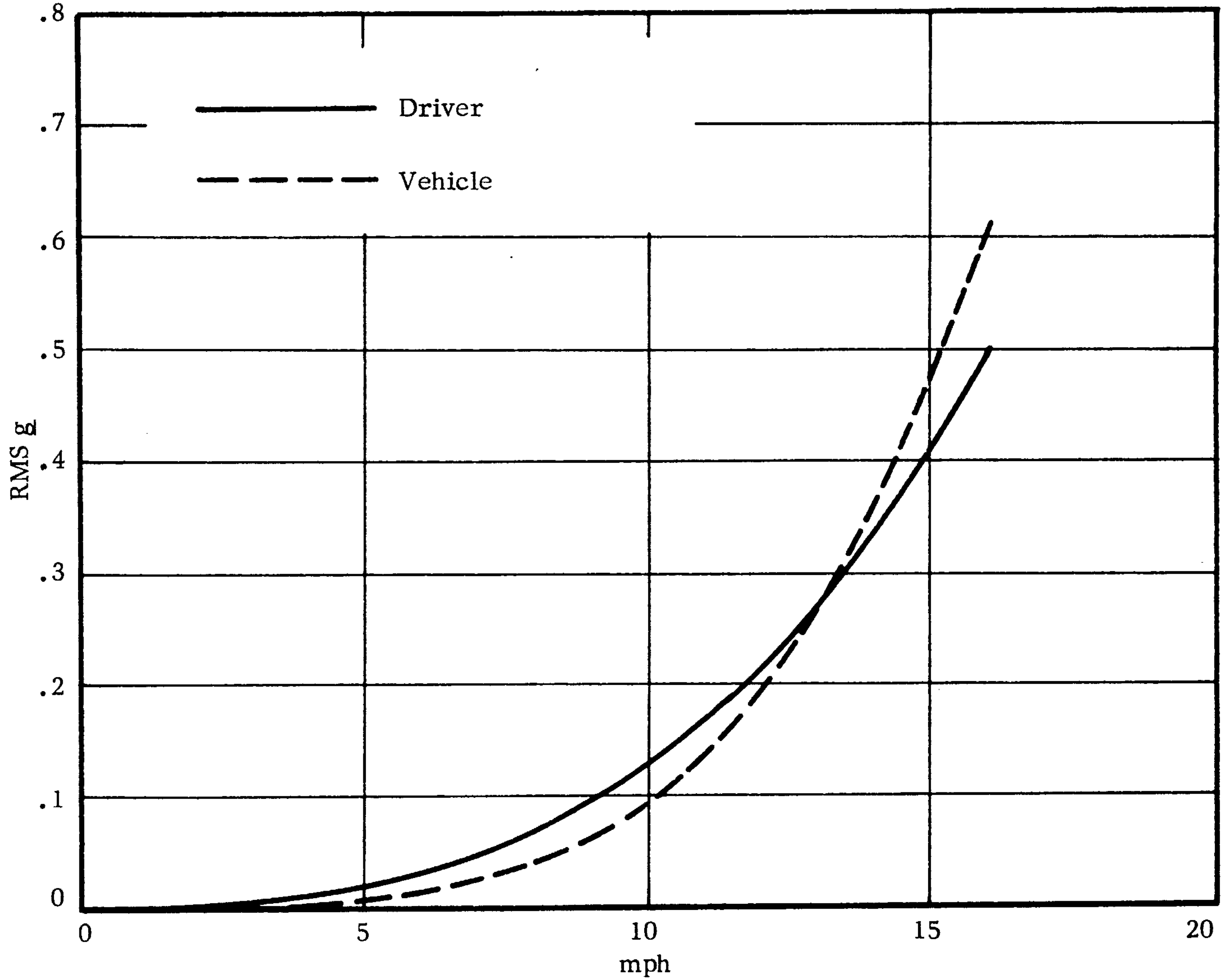

Fig. 7. CROSS-COUNTRY RESULTS: VERTICAL, COURSE #2
(RMS g vs. average vehicle speed)

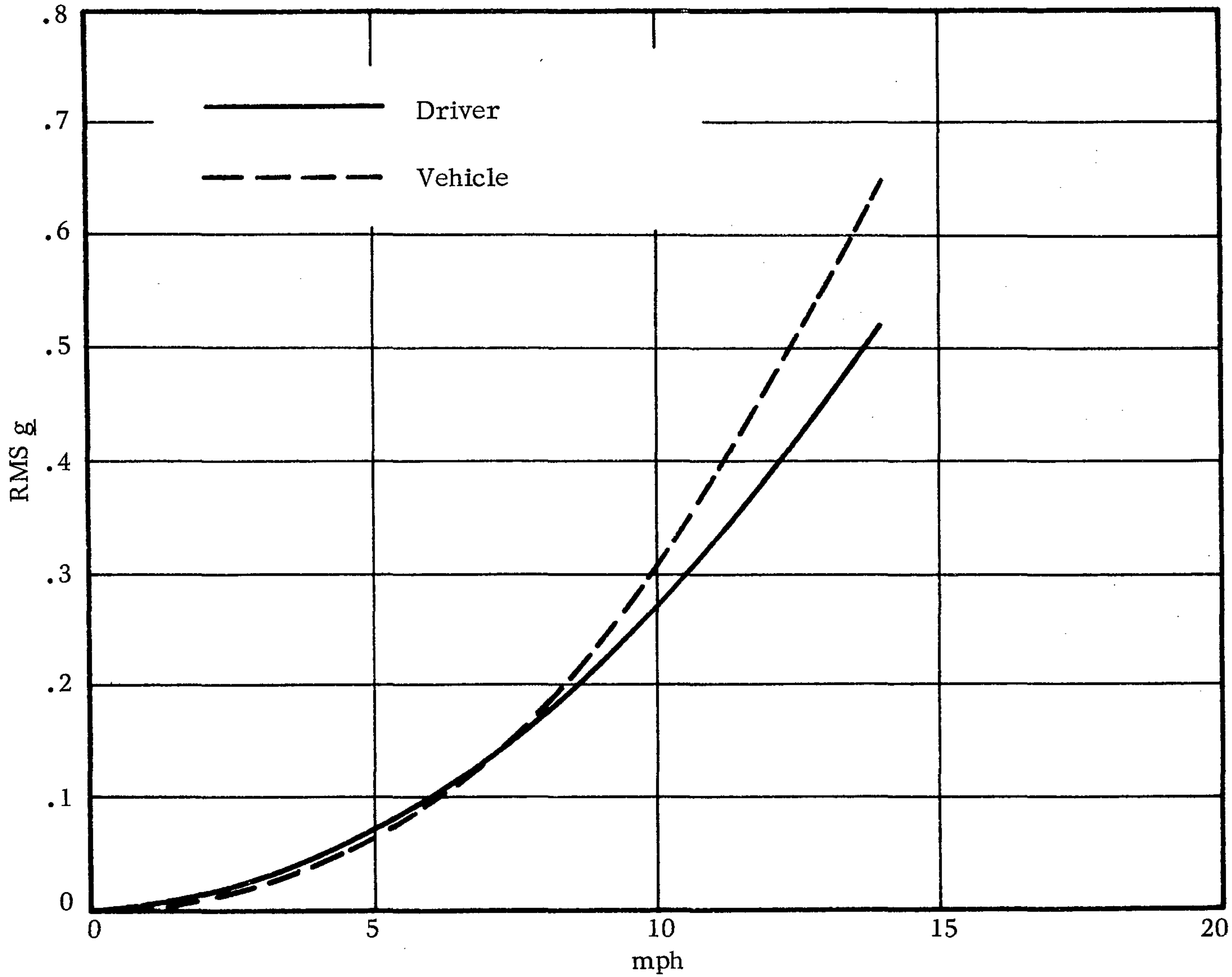

Fig. 8. CROSS-COUNTRY RESULTS: VERTICAL, COURSE #3
(RMS g vs. average vehicle speed)

A comprehensive description of maximum tolerable g level will require more tests to show what effects these variables have. The best that can be done now is to describe the environment that was tolerated during this test.

The RMS g levels can be described easily: the average of all cross-country runs was approximately one-third g, and the maximum RMS g level for any one trial was approximately one-half g. The amplitude analyses give more detailed descriptions, which will probably be more useful for comparison with future work. Figures 9 through 11 show distribution plots for the combined results of all cross-country trials.

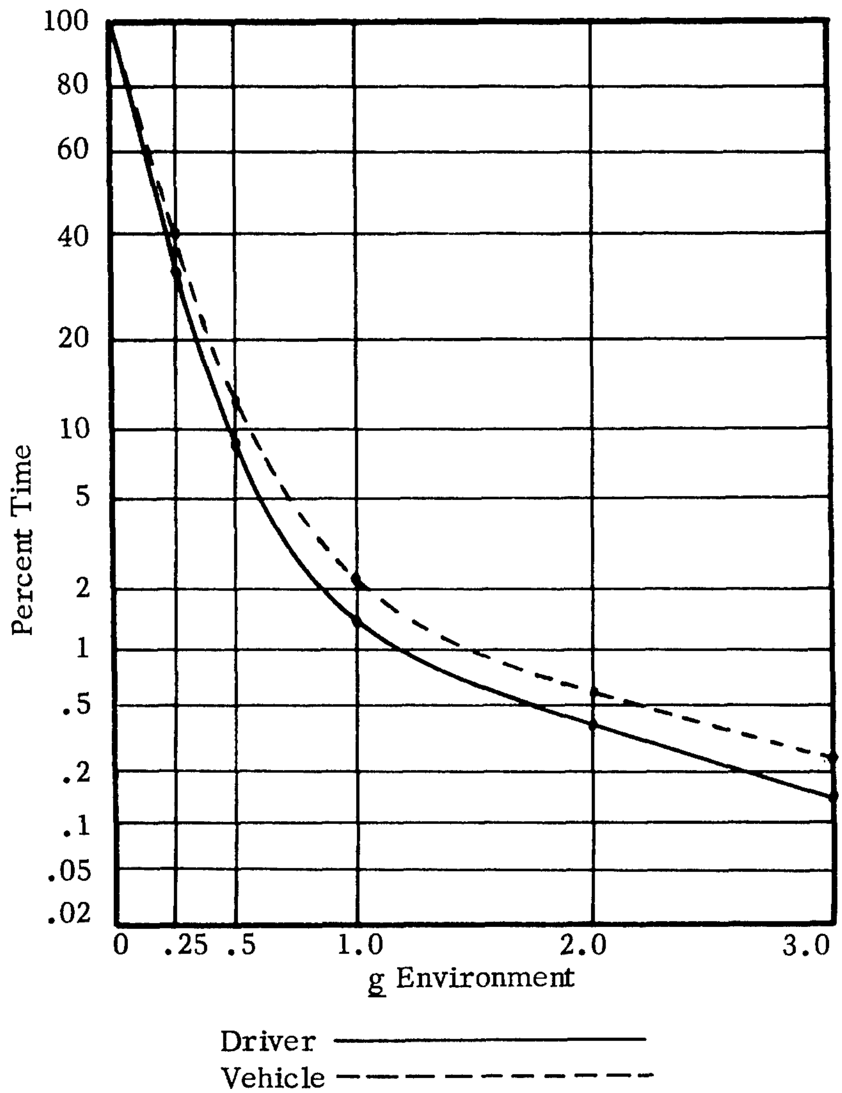

Fig. 9. COMBINED RESULTS: VERTICAL-AMPLITUDE ANALYSIS
(Mean percentage of time g environment exceeds a given limit.)

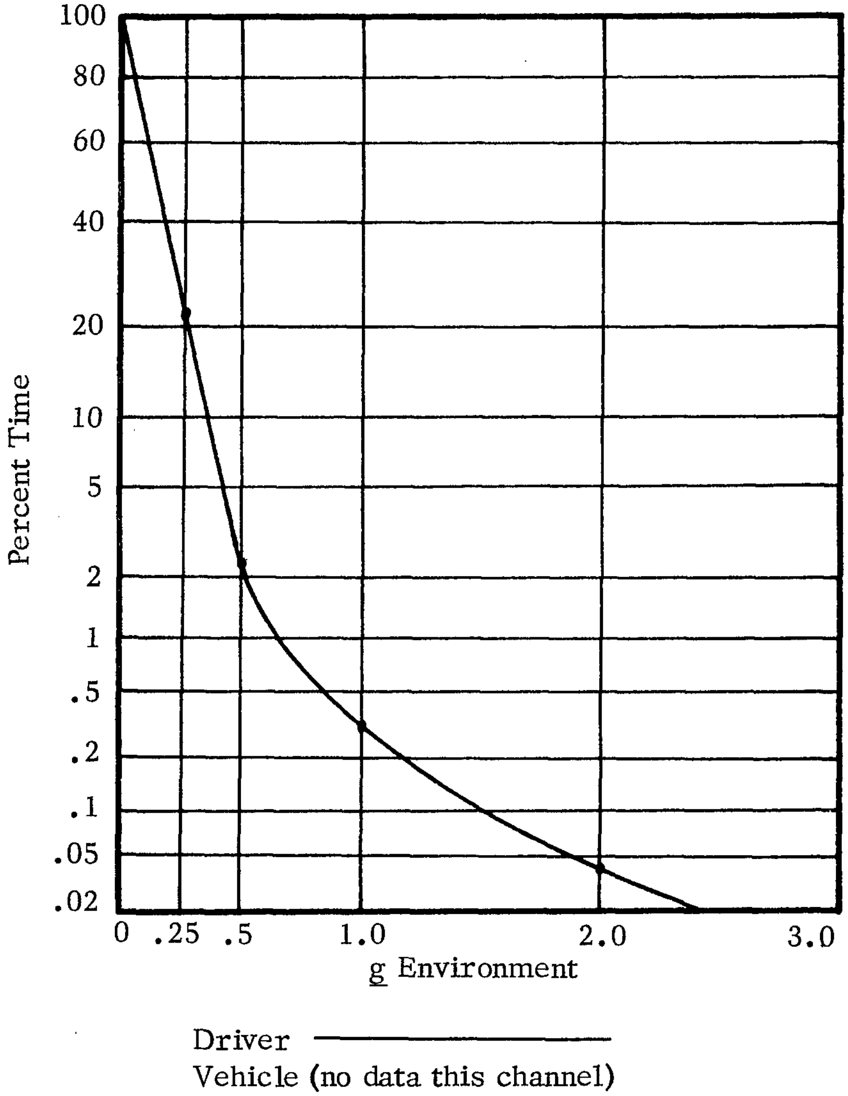

Fig. 10. COMBINED RESULTS: LONGITUDINAL-AMPLITUDE ANALYSIS
(Mean percentage of time g environment exceeds a given limit.)

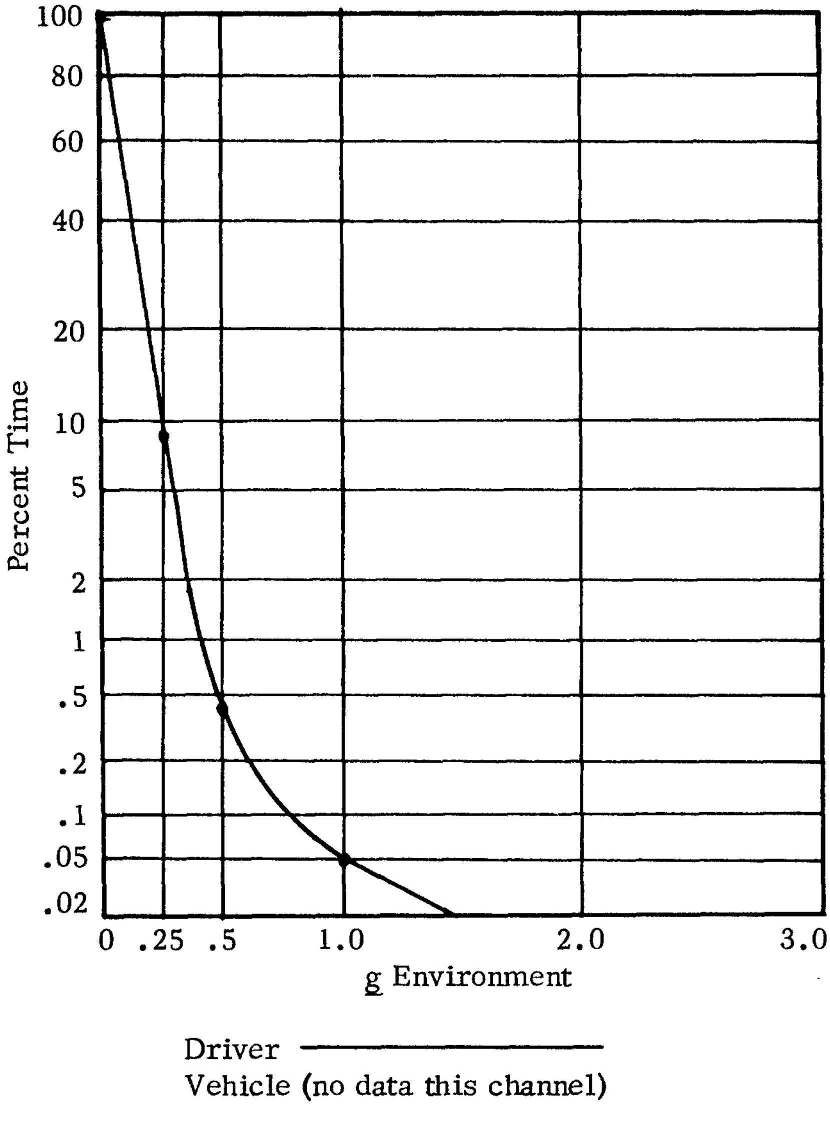

Fig. 11. COMBINED RESULTS: TRANSVERSE-AMPLITUDE ANALYSIS
(Mean percentage of time g environment exceeds given limit.)

CONCLUSIONS

This study investigated the g environment that an M60 tank driver experiences while driving over various types of cross-country terrain. The relationship between the driver's vertical g loading and vehicle speed for the M60 tank has been measured on two Aberdeen Proving Ground cross-country courses (Perryman Courses #2 and #3). The results indicated these conclusions:

a. The weakness of the M60 tank's suspension system is a major factor limiting vehicle mobility at maximum cross-country speeds. The number of breakdowns experienced in this study surely indicates that slower speeds would have to be used in battle.

b. This study indicated driver tolerance is one-half g RMS acceleration.

RECOMMENDATIONS

Future work in this field should:

a. Investigate how g environments differ in the various crew positions of an M60 tank and determine which position is most critical in limiting vehicle mobility.

b. Investigate how longer exposure periods in the g environment affect tolerance levels of the tank driver and other crew members.

c. Investigate fully how the g environment varies with a greater variety of terrain features.

d. Investigate how g environment depends on the suspension characteristics of various armored vehicles.

e. Determine if vehicles with higher power-to-weight ratios would have been able to go faster, thereby raising the average g level.

APPENDIX A

SUSPENSION-SYSTEM FAILURES DURING

M60 DRIVER VIBRATIONAL-ENVIRONMENT STUDY

INTRODUCTION

The Human Engineering Laboratories' M60A1 driver-environment study, conducted from 1 June to 15 July 1964, encountered many difficulties with the tank's suspension system. These difficulties included such things as bending, fatigue failure, and shock failure of various suspension components.

COURSES AND FAILURES

Phase I

Standard courses of the Munson Test Area were used first in the mobility study. These courses were the 6" washboard and the 6-12" staggered-bump courses.

The 6" washboard course is made up of concrete sections of uniform wave design, with a 6" amplitude and 6' between crests. This course is 800 feet long. Each subject traveled the course twice. Subjects were instructed to drive at 16 mph, and the driver had sufficient distance before the course began to accelerate to the prescribed speed.

The 6-12" staggered-bump course -- obviously more severe -- was traveled at 5 mph. The course is 260 feet long, with 6" bumps for the first 130 feet and 12" bumps for the remainder of the course. The bumps are intermittently staggered. There were nine drivers in the study, but the test had to be stopped before two of them had their second trials on the staggered-bump course. The number three and four road-wheel arms on both sides were bent upward so the tops of the road wheels turned against the stops.

There was one additional failure on the standard course -- a broken shock absorber on the right front wheel.

Phase II

The second phase of the mobility study was conducted on the cross-country terrain of the Perryman complex. Cross-country Course #2 was used first. This course, considered moderately rough, is graded native soil with intermittently spaced dips and bumps. This course is 1.8 miles long and, on the testing days, its surface was dry and dusty except for mud and shallow water in the holes.

In our cross-country testing, each driver was instructed to travel the course as fast as possible without injuring himself. The drivers used two driving positions: open-hatch and closed-hatch. The first four runs on Course #2 were closed-hatch runs. Testing was stopped after the fourth run, because the right-front road-wheel hub was completely destroyed. There were no bearings left in the hub, and the road-arm spindle had ridden on the bottom of the hub until the bottom of the spindle had worn flat. This same failure in the same road-wheel position occurred five different times during testing on Course #2. These failures occurred after a minimum of two runs and a maximum of four runs, with times per run ranging from 6 1/2 minutes to 11 minutes and at speeds between eight and 24 mph. After each failure, the road-wheel arm and complete assembly (including hub, bearings, seals, etc.) were replaced, and the entire suspension system was serviced before testing was resumed. After the second road-arm failure on Course #2, testing began on Course #3. Course #3 of the Perryman complex is considered rough. It is native soil with graded bumps, holes, shallow water, and mud. The graded bumps are spaced intermittently, with amplitudes between two to eight feet. The course is approximately three miles long, but our testing used only half of the course on each run. Running times ranged from 6 1/2 minutes to 12 minutes, with speeds between 7 mph and 13 mph. On this course the right-front road-wheel arm hub and spindle failed once in the same way as on Course #2. After testing on this course was completed, testing on Course #2 was resumed and completed.

One other suspension-system failure occurred periodically throughout our environment study: fractured snubbers on both the left and right sides.

One remaining failure was not related to the suspension system: high-level g's produced by terrain and driver's body weight bent the driver's seat assembly and, finally, fractured it about halfway through the cross-country driving tests. A second seat assembly was installed. This seat was also severely bent by the time the driver-environment study was finished.

The following photographs are typical of these failures.

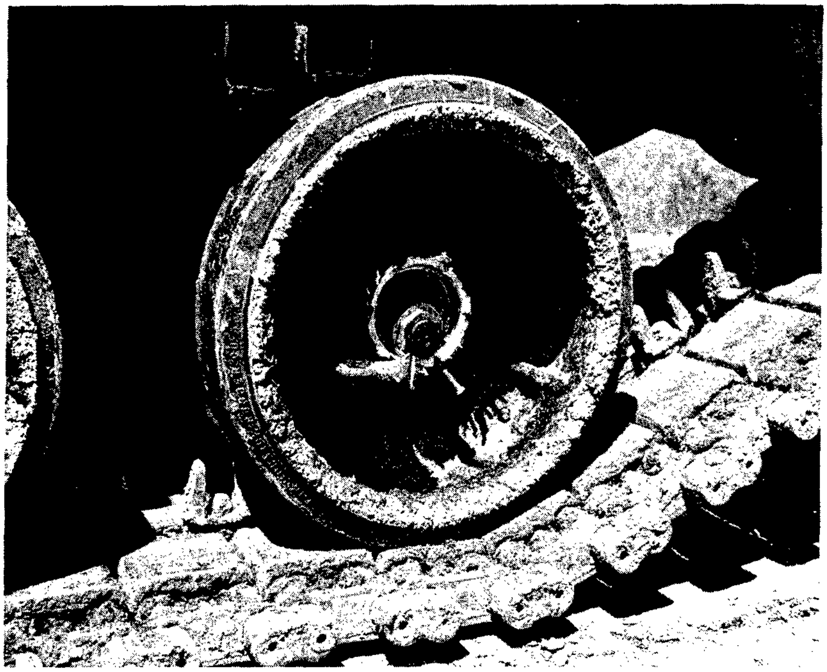

Fig. 1A. RIGHT-FRONT ROAD-WHEEL HUB

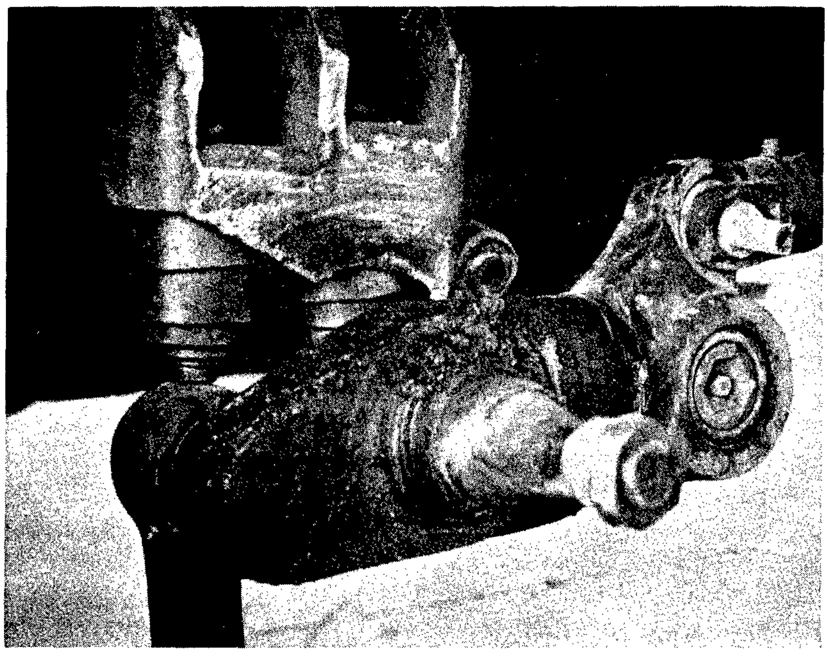

Fig. 2A. RIGHT-FRONT ROAD-WHEEL ARM

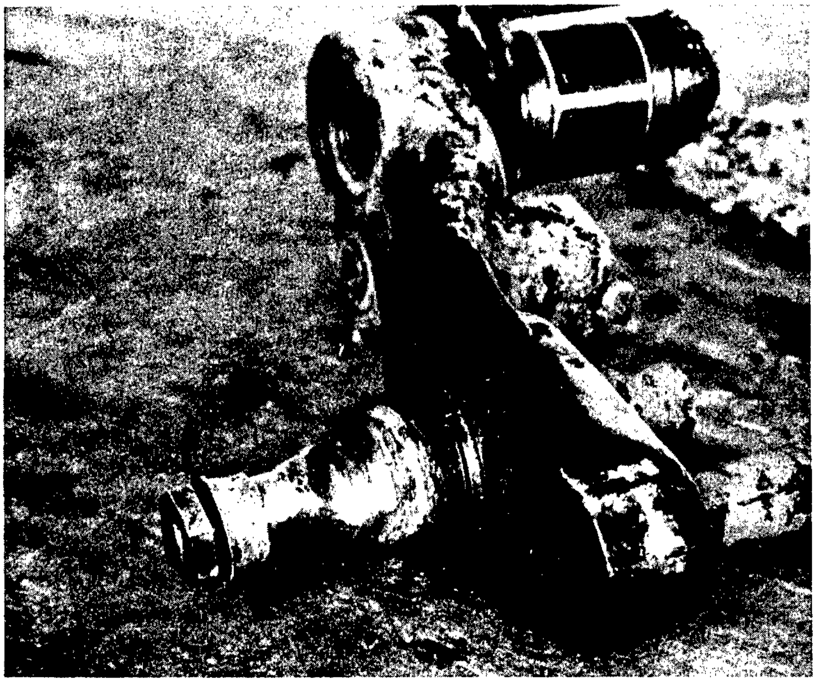

Fig. 3A. RIGHT-FRONT ROAD-WHEEL ARM

Fig. 4A. RIGHT-FRONT ROAD-WHEEL SPINDLE

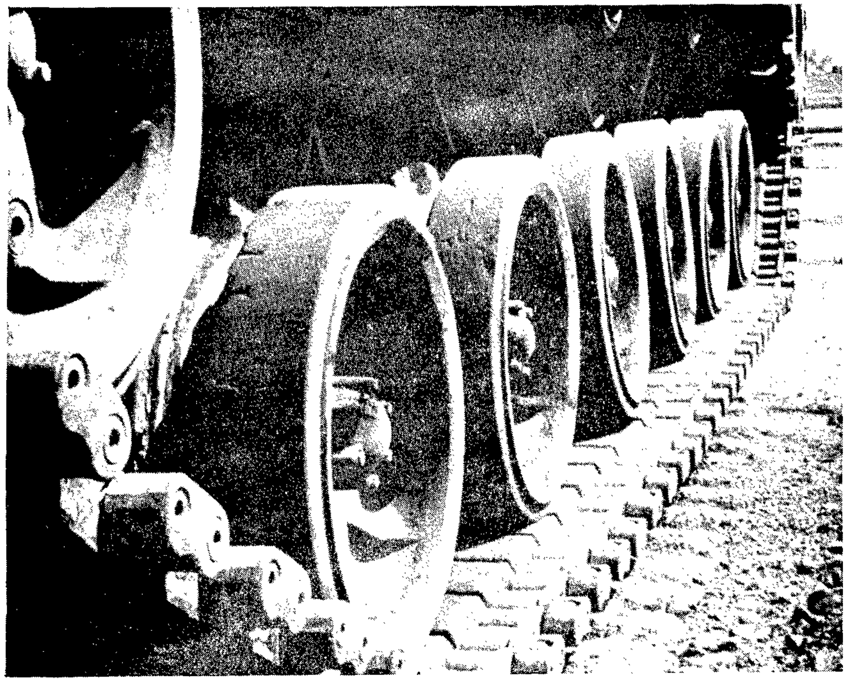

Fig. 5A. NUMBERS 3 AND 4 ROAD-WHEEL ARMS BENT

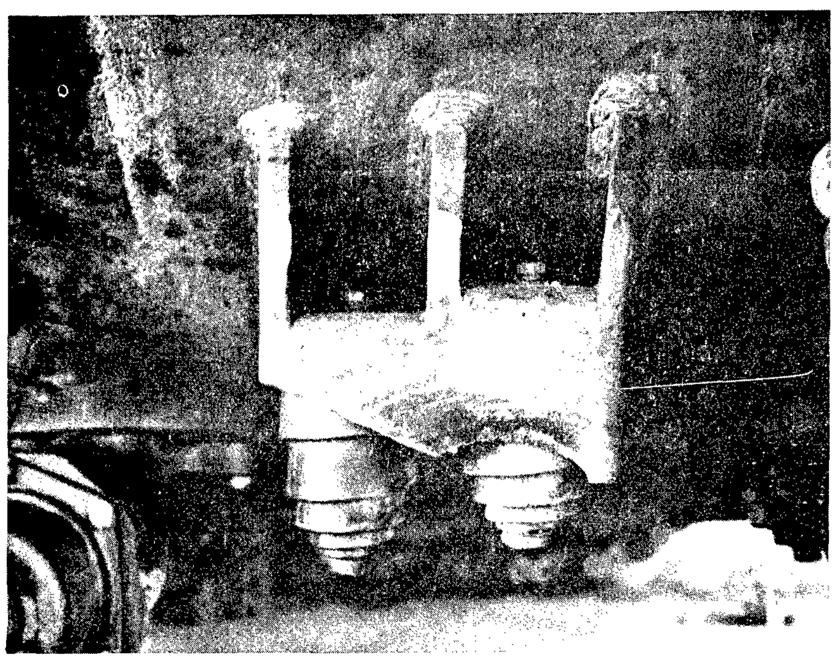

Fig. 6A. RIGHT-FRONT ROAD-WHEEL-ARM SNUBBERS

APPENDIX B

M60A1 DRIVER VIBRATIONAL-ENVIRONMENT STUDY

(Raw Data)

TABLE 1B

Standard-Course Data: RMS g

Six-Inch Washboard Course

	Vertical		Transverse		Longitudinal	
Subject	Driver	Vehicle	Driver	Vehicle	Driver	Vehicle
1	--	--	--	--	--	--
2	.11	.25	--	--	.13	.11
3	.10	.17	--	--	.11	--
4	.12	.19	--	--	.13	--
5	.12	.27	--	--	.10	.06
6	.14	.28	--	--	.12	.17
7	.13	.26	--	--	.12	.19
8	.16	.29	--	--	--	.18
9	.14	.30	--	--	--	.10
Mean	.13	.25	--	--	.12	.14
S.D.	.018	.044	--	--	.011	.035

TABLE 2B

Standard-Course Data: RMS g

6-12 Inch Staggered-Bump Course

Subject	Vertical		Transverse		Longitudinal	
	Driver	Vehicle	Driver	Vehicle	Driver	Vehicle
1	--	--	--	--	--	--
2	.22	.23	--	--	--	--
3	--	--	--	--	--	--
4	.20	.21	--	--	.29	--
5	.20	.21	--	--	--	--
6	--	--	--	--	--	--
7	.19	.21	--	--	.23	--
8	.20	.24	--	--	.16	--
9	.24	.24	--	--	.25	--
Mean	.21	.22	--	--	.23	--
S.D.	.017	.014	--	--	.047	--

TABLE 3B

Cross-Country: RMS g

Course #2, Open Hatch

Subject	Test	Vertical		Longitudinal		Transverse		mph
		Driver	Vehicle	Driver	Vehicle	Driver	Vehicle	
1	6E	.21	.15	--	--	.09	--	10.4
2	2E	.56	.60	--	--	.10	--	16.6
3	8E	.17	.17	--	--	.06	--	10.6
4	1E	.49	.58	--	--	.18	--	16.6
5	5E	.11	.05	--	--	.06	--	10.1
6	3E	.41	.49	--	--	.13	--	15.2
7	4E	.49	.59	--	--	.10	--	16.6
8	7E	.09	.08	--	--	.05	--	9.8
9	9E	--	--	--	--	--	--	--
Mean		.316	.339	--	--	.096	--	13.24
$\underline{r}$		.98	.996	--	--	.77	--	

TABLE 4B

Cross-Country: RMS g

Course #3, Open Hatch

Subject	Test	Vertical		Longitudinal		Transverse		mph
		Driver	Vehicle	Driver	Vehicle	Driver	Vehicle	
1	7D	.22	.25	.08	--	.08	--	9.8
2	3C	.48	.53	.32	--	.15	--	14.0
3	1C	.27	.30	.13	--	.12	--	10.4
4	8D	.42	.51	.19	--	.14	--	12.7
5	5C	.15	.19	.12	--	.21	--	10.4
6	2C	.41	.44	.30	--	.11	--	10.0
7	6D	.35	.40	.22	--	.06	--	10.3
8	4C	.18	.23	.17	--	.09	--	9.5
9	9D	.24	--	.09	--	.07	--	9.8
Mean		.302	.356	.180	--	.114	--	10.77
r		.74	.77	.56	--	.46	--	

TABLE 5B

Cross-Country: RMS g

Course #3, Closed Hatch

Subject	Test	Vertical		Longitudinal		Transverse		mph
		Driver	Vehicle	Driver	Vehicle	Driver	Vehicle	
1	7C	.53	.62	.25	--	.16	--	13.6
2	3D	.39	.47	.20	--	.14	--	10.5
3	1D	.26	.27	.17	--	.14	--	8.9
4	8C	.42	.47	.25	--	.17	--	11.1
5	5D	.17	.15	.18	--	.07	--	7.6
6	2D	.30	.38	.17	--	.11	--	10.7
7	6C	.34	.38	.15	--	.09	--	10.2
8	4D	.18	.20	.15	--	.14	--	8.7
9	9C	.23	.27	.10	--	.14	--	10.1
Mean		.313	.357	.180	--	.129	--	10.16
r		.92	.95	.56	--	.58	--	

TABLE 6B

Amplitude Analysis

Vertical -- Driver, Cross-Country Course #3

Subject	Test	Driving Condition[a]	Percent Time Above Levels .25g	.50g	1.0g	2.0g	3.0g	mph
1	7C	CH	52.2	22.27	3.742	1.0121	.4823	13.6
	7D	OH	26.1	3.69	.430	.0435	.0019	9.8
2	3C	OH	52.1	19.89	3.984	1.0743	.4273	14.0
	3D	CH	40.8	7.75	2.569	.6881	.2624	10.5
3	1C	OH	27.3	4.52	.487	.0206	.0066	10.4
	1D	CH	28.2	4.61	.762	.1368	.0513	8.9
4	8C	CH	45.4	16.66	3.068	.8474	.3974	11.1
	8D	OH	46.3	16.35	2.550	.6316	.2796	12.7
5	5C	OH	21.1	1.98	.089	.0151	.0000	10.4
	5D	CH	24.0	.64	.020	.0039	.0029	7.6
6	2C	OH	42.3	12.43	2.125	.3743	.1399	10.0
	2D	CH	33.8	9.23	1.832	.3908	.1470	10.7
7	6C	CH	23.4	6.43	1.112	.2011	.0831	10.2
	6D	OH	39.8	10.08	1.758	.3702	.1437	10.3
8	4C	OH	25.3	2.65	.211	.0141	.0023	9.5
	4D	CH	20.3	2.05	.311	.0099	.0010	8.7
9	9C	CH	26.6	4.85	.691	.0737	.0224	10.1
	9D	OH	27.9	4.52	.404	.0231	.0048	9.8
Mean			33.49	8.37	1.452	.3290	.1360	11.24
S.D.			10.72	6.57	1.292	.3690	.1640	4.93
r			.81	.88	.84	.84	.84	

[a] CH -- Closed-Hatch Driving Position
OH -- Open-Hatch Driving Position

TABLE 7B

Amplitude Analysis

Vertical -- Vehicle, Cross-Country Course #3

Subject	Test	Driving Condition[a]	Percent Time Above Levels .25g	.50g	1.0g	2.0g	3.0g	mph
1	7C	CH	54.6	24.92	5.527	1.5284	.7033	13.6
	7D	OH	31.7	6.26	.866	.1318	.0187	9.8
2	3C	OH	53.8	22.12	4.477	1.3232	.5770	14.0
	3D	CH	44.1	15.00	3.197	.9149	.3784	10.5
3	1C	OH	36.6	7.85	1.205	.1696	.0310	10.4
	1D	CH	29.8	5.86	1.078	.1764	.0696	8.9
4	8C	CH	47.5	17.42	3.353	.8723	.3972	11.1
	8D	OH	53.0	23.20	3.604	.7129	.3721	12.7
5	5C	OH	24.2	2.92	.208	.0375	.0039	10.4
	5D	CH	20.4	1.40	.049	.0142	.0035	7.6
6	2C	OH	47.2	17.11	2.845	.4517	.2365	10.0
	2D	CH	43.0	13.05	2.165	.5543	.1861	10.7
7	6C	CH	39.5	11.02	1.861	.4174	.1456	10.2
	6D	OH	46.0	13.85	2.183	.4744	.1947	10.3
8	4C	OH	32.5	5.99	.725	.0093	.0037	9.5
	4D	CH	25.5	3.42	.470	.0218	.0033	8.7
9	9C	CH	33.9	6.84	1.011	.1647	.0674	10.1
	9D	OH	--	--	--	--	--	9.8
Mean			39.0	11.66	2.049	.4691	.1995	11.24
S.D.			10.75	7.43	1.579	.4650	.2165	4.93

[a] CH -- Closed-Hatch Driving Position
OH -- Open-Hatch Driving Position

TABLE 8B

Amplitude Analysis

Vertical -- Driver, Cross-Country Course #2

Subject	Test	Percent Time Above Levels .25g	.50g	1.0g	2.0g	3.0g	mph
1	6E	36.5	2.53	.051	.0019	--	10.4
2	2E	49.5	21.15	3.590	.9783	.3831	16.6
3	8E	19.7	1.61	.101	.0060	--	10.6
4	1E	47.5	18.09	3.665	1.0837	.4535	16.6
5	5E	5.1	.07	.019	.0009	--	10.1
6	3E	43.1	15.41	2.442	1.0972	.2126	15.2
7	4E	45.4	15.14	3.407	.9447	.4106	16.6
8	7E	6.1	.07	.009	.0009	--	9.8
9	9E	--	--	--	--	--	--
Mean		31.6	9.26	1.661	.5142	.1825	13.24
S.D.		18.6	8.98	1.766	.5490	.2070	
r		.88	.98	.995	.98	.96	

TABLE 9B

Amplitude Analysis

Vertical -- Vehicle, Cross-Country Course #2

Subject	Test	Percent Time Above Levels .25g	.50g	1.0g	2.0g	3.0g	mph
1	6E	17.6	1.59	.060	.0147	.0041	10.4
2	2E	53.4	23.87	4.828	1.4631	.6157	16.6
3	8E	22.1	2.25	.130	.0157	.0037	10.6
4	1E	54.4	28.34	4.889	1.2880	.6007	16.6
5	5E	2.8	.14	.033	.0148	.0037	10.1
6	3E	48.0	18.72	3.570	.9399	.3937	15.2
7	4E	52.9	24.82	5.054	1.4860	.6342	16.6
8	7E	4.6	.18	.032	.0156	.0036	9.8
9	9E	--	--	--	--	--	--
Mean		32.0	12.49	2.325	.6547	.2824	13.24
S.D.		22.6	12.52	2.460	.703	.3069	

TABLE 10B

Amplitude Analysis

Transverse -- Driver, Cross-Country Course #3

Subject	Test	Driving Condition[a]	Percent Time Above Levels .25g	.50g	1.0g	2.0g	3.0g	mph
1	7C	CH	--	--	--	--	--	13.6
	7D	OH	4.7	.33	.020	.0200	.0028	9.8
2	3C	OH	13.4	1.10	.129	.0219	.0062	14.0
	3D	CH	15.9	.84	.128	.0153	.0025	10.5
3	1C	OH	14.1	.33	.003	.0013	.0013	10.4
	1D	CH	2.8	.06	.060	.0169	.0028	8.9
4	8C	CH	11.6	1.03	.199	.0365	.0349	11.1
	8D	OH	15.2	.52	.077	.0291	.0033	12.7
5	5C	OH	41.2	.01	.008	.0075	.0075	10.4
	5D	CH	.8	.10	.020	.0126	.0033	7.6
6	2C	OH	11.1	.27	.044	.0236	.0025	10.0
	2D	CH	8.4	.56	.056	.0191	.0030	10.7
7	6C	CH	4.6	.15	.008	.0079	.0025	10.2
	6D	OH	2.6	.12	.023	.0228	.0028	10.3
8	4C	OH	4.2	.11	.020	.0165	.0099	9.5
	4D	CH	.9	.11	.015	.0148	.0019	8.7
9	9C	CH	5.0	.01	.005	.0047	.0045	10.1
	9D	OH	1.9	.10	.016	.0155	.0043	9.8
Mean			9.3	.34	.049	.0169	.0056	11.24
S.D.			9.4	.11	.054	.0084	.0076	

[a] CH -- Closed-Hatch Driving Position
OH -- Open-Hatch Driving Position

TABLE 11B

Amplitude Analysis

Transverse -- Driver, Cross-Country Course #2

Subject	Test	Percent Time Above Levels .25g	.50g	1.0g	2.0g	3.0g	mph
1	6E	3.7	.53	.010	.0100	.0042	10.4
2	2E	6.4	.59	.033	.0330	.0035	16.6
3	8E	2.1	.18	.001	.0009	.0009	10.6
4	1E	18.6	2.13	.279	.0049	.0049	16.6
5	5E	.6	.06	.021	.0205	.0023	10.1
6	3E	8.7	.60	.031	.0202	.0098	15.2
7	4E	6.7	.76	.039	.0374	.0036	16.6
8	7E	.1	.09	.007	.0009	.0009	9.8
9	9E	--	--	--	--	--	--
Mean		5.9	.61	.053	.0167	.0038	13.24
S.D.		5.6	.63	.087	.0125	.0027	

TABLE 12B

Amplitude Analysis

Longitudinal -- Driver, Cross-Country Course #3

Subject	Test	Driving Condition[a]	Percent Time Above Levels .25g	.50g	1.0g	2.0g	3.0g	mph
1	7C	CH	25.5	5.60	1.151	.1760	.0501	13.6
	7D	OH	10.8	.28	.009	.0000	.0000	9.8
2	3C	OH	23.4	8.32	1.149	.1180	.0445	14.0
	3D	CH	21.5	3.17	.432	.0628	.0225	10.5
3	1C	OH	12.1	1.08	.107	.0356	.0079	10.4
	1D	CH	22.1	2.31	.121	.0270	.0065	8.9
4	8C	CH	41.6	2.19	.413	.0403	.0151	11.1
	8D	OH	19.0	2.75	.488	.0488	.0166	12.7
5	5C	OH	11.7	.40	.005	.0000	.0000	10.4
	5D	CH	32.0	2.14	.039	.0270	.0028	7.6
6	2C	OH	23.9	5.67	.896	.0613	.0238	10.0
	2D	CH	18.3	2.46	.287	.0124	.0038	10.7
7	6C	CH	11.3	.66	.029	.0250	.0019	10.2
	6D	OH	29.5	3.81	.545	.0230	.0230	10.3
8	4C	OH	21.8	.79	.070	.0473	.0037	9.5
	4D	CH	27.1	.70	.023	.0230	.0028	8.7
9	9C	CH	6.6	.19	.040	.0380	.0029	10.1
	9D	OH	6.4	.26	.047	.0236	.0014	9.8
Mean			20.26	2.354	.3238	.0441	.0127	11.24
S.D.			9.05	2.220	.3760	.0225	.0145	4.93

[a] CH -- Closed-Hatch Driving Position
OH -- Open-Hatch Driving Position

TABLE 13B

Average Speeds in mph

Subject	Cross-Country Course #2 Open Hatch	Cross-Country Course #2 Closed Hatch	Cross-Country Course #2 Combined	Cross-Country Course #3 Open Hatch	Cross-Country Course #3 Closed Hatch	Cross-Country Course #3 Combined	All Courses Combined
1	10.4	11.7	11.1	9.8	13.6	11.7	11.4
2	16.6	--	16.6	14.0	10.5	12.3	13.7
3	10.6	--	10.6	10.4	8.9	9.7	10.0
4	16.6	13.6	15.1	12.4	11.1	11.8	13.4
5	10.1	--	10.1	10.4	7.6	9.0	9.4
6	15.2	--	15.2	10.0	10.7	10.4	12.0
7	16.6	12.0	14.3	10.3	10.2	10.3	12.3
8	9.8	11.6	10.7	9.5	8.7	9.1	9.9
9	--	13.6	13.6	9.8	10.1	9.9	11.2
Mean	13.2	12.5	13.0	10.7	10.2	10.4	11.5

TABLE 14B

Subject Data

Subject	Height (in.)	Weight (lb.)	Age (yr.)	No. Years Experience
1	66	148	23	3
2	74	195	31	10
3	69	210	31	2
4	75	180	32	10
5	70	180	23	2
6	71	165	24	5
7	72	160	20	3
8	72	160	22	1/2
9	74	170	25	1/2
Mean	71 1/2	174	26	4

APPENDIX C

M60 DRIVER VIBRATIONAL-ENVIRONMENT STUDY

DATA REDUCTION

The data reduction involved two phases: (a) determining the RMS g for each run, and (b) determining the amplitude distributions (the percent of the time that the absolute value of the accelerations exceeded given levels). The equipment for computing RMS g is shown in Figure 1C. The tape-recorded data were played back at real speed, one channel at a time, into amplifier A_1. A_1 served two purposes: (a) increasing the signal level by a factor of ten, and (b) acting as a low-pass filter with a cutoff of about 30 cycles per second (cps), to eliminate tape noise. Amplifier A_2 computed the absolute value of the signal, and its output was fed to a nonlinear resistance. The current through this nonlinear resistance was proportional to the square of the applied voltage over a 20-to-1 range of input voltages. Because the nonlinear resistance is temperature sensitive, it was kept at a constant temperature of $70^\circ \pm 2^\circ$ F. Amplifier A_3 was a low-impedance driver for the nonlinear resistance. Amplifier A_4 integrated the output of the nonlinear resistance, giving (time) x $(g)^2$.

An automatic reset monitored A_4's output and, when it exceeded 11 volts, discharged a feedback capacitator within two to three milliseconds. A_4's output drove the galvanometer of a CEC oscillographic recorder. In addition, there were provisions for recording the signal's momentary value and its cumulative mean. Recording the mean had originally been intended as a check on the overall zeroing, during both recording and playback. However, spot checks revealed that zero errors amounted to less than .02 g. Since these means served no useful purpose, they were discontinued. A zero-g and 2-g calibration preceded each run. The 2-g calibration was used, for the period of that run, as the reference. The computational formula for determining RMS g is:

$$\text{RMS } g = 2 \; \frac{(\text{Length of 2-g run})^{1/2}}{(\text{Total deflection of 2-g run})^{1/2}} \cdot \frac{(\text{Total deflection of data run})^{1/2}}{(\text{Length of data run})^{1/2}}$$

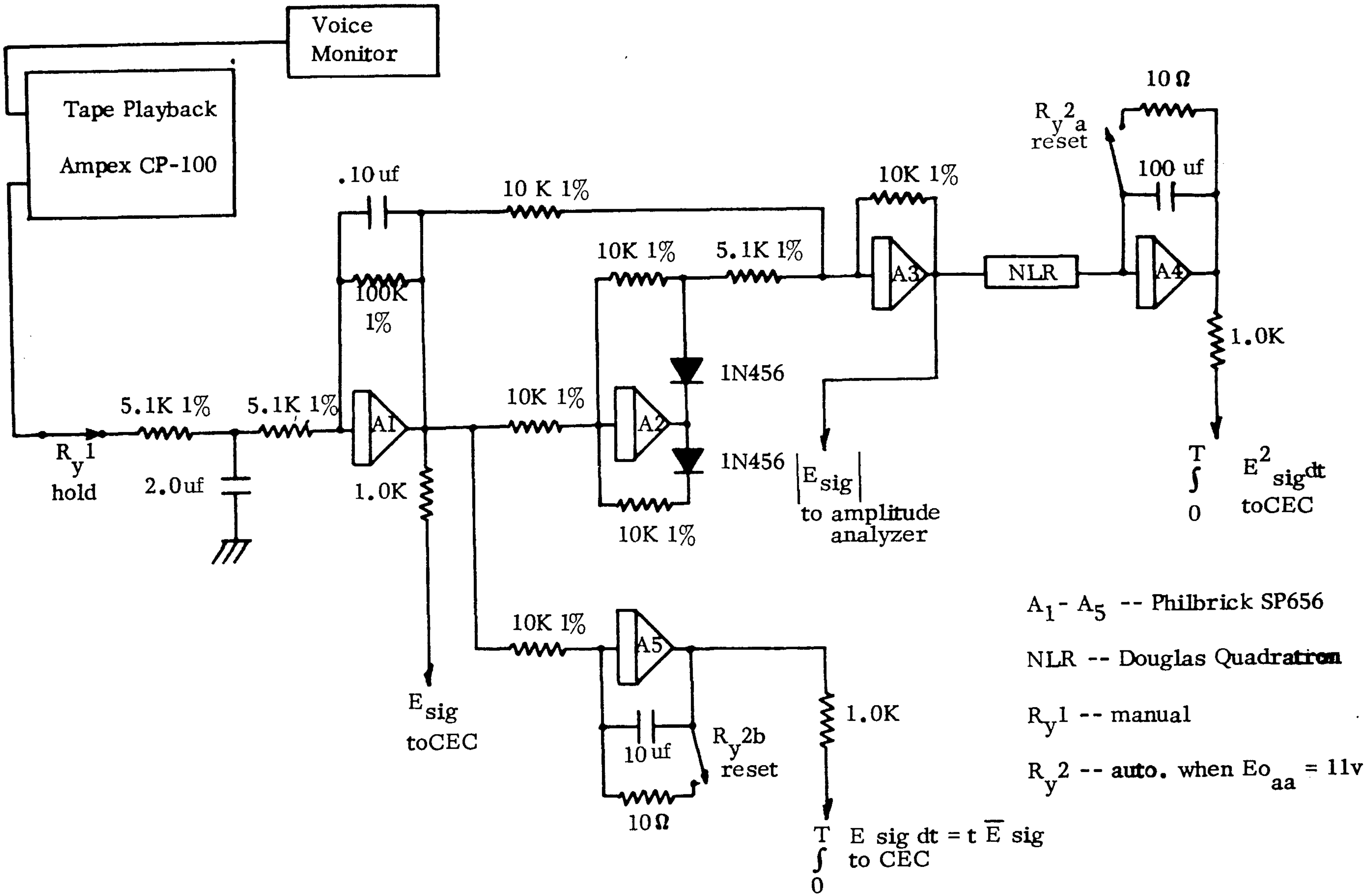

Fig. 1C. REDUCTION CIRCUIT: RMS g's

The system was checked with both DC and AC voltages, and it was accurate within about two percent for a 10-to-1 change in input-signal level. Such accuracy was considered adequate for the purposes of this study, provided that A_1's gain was increased for extremely low levels (less than .1 g RMS).

Figure 2C shows how the amplitude analyzer functioned. The Dana amplifiers were used as level detectors and, with the diode-resistor networks in their output, supplied a constant current to the Kintel amplifiers which, in turn, were connected as integrators. For example, amplifier #1 has zero volts DC as its reference; whenever the signal exceeded zero volts, which was 100 percent of the time, a constant current was supplied to the corresponding integrator. This channel served as the clock. Channel #2 was set up with a reference voltage that corresponded to .25 g and, whenever the signal exceeded this value, the corresponding integrator integrated. At the conclusion of a run, a digital-voltmeter system read and printed the voltages on each of the six integrators. The percentage of the time the signal exceeded a given level could then be calculated easily, because the factors arising from the different integrator-input resistors were known.

The system's drift over a 10-minute period, with no input, was less than 0.1 percent of any channel's capacity. It should be noted that the Dana amplifiers recover from overload in only a few milliseconds. Overall repeatability and accuracy were better than one percent, as measured by playing the same run through twice.

It should be noted that this is not the most convenient sort of amplitude analyzer; however, it was designed around available equipment.

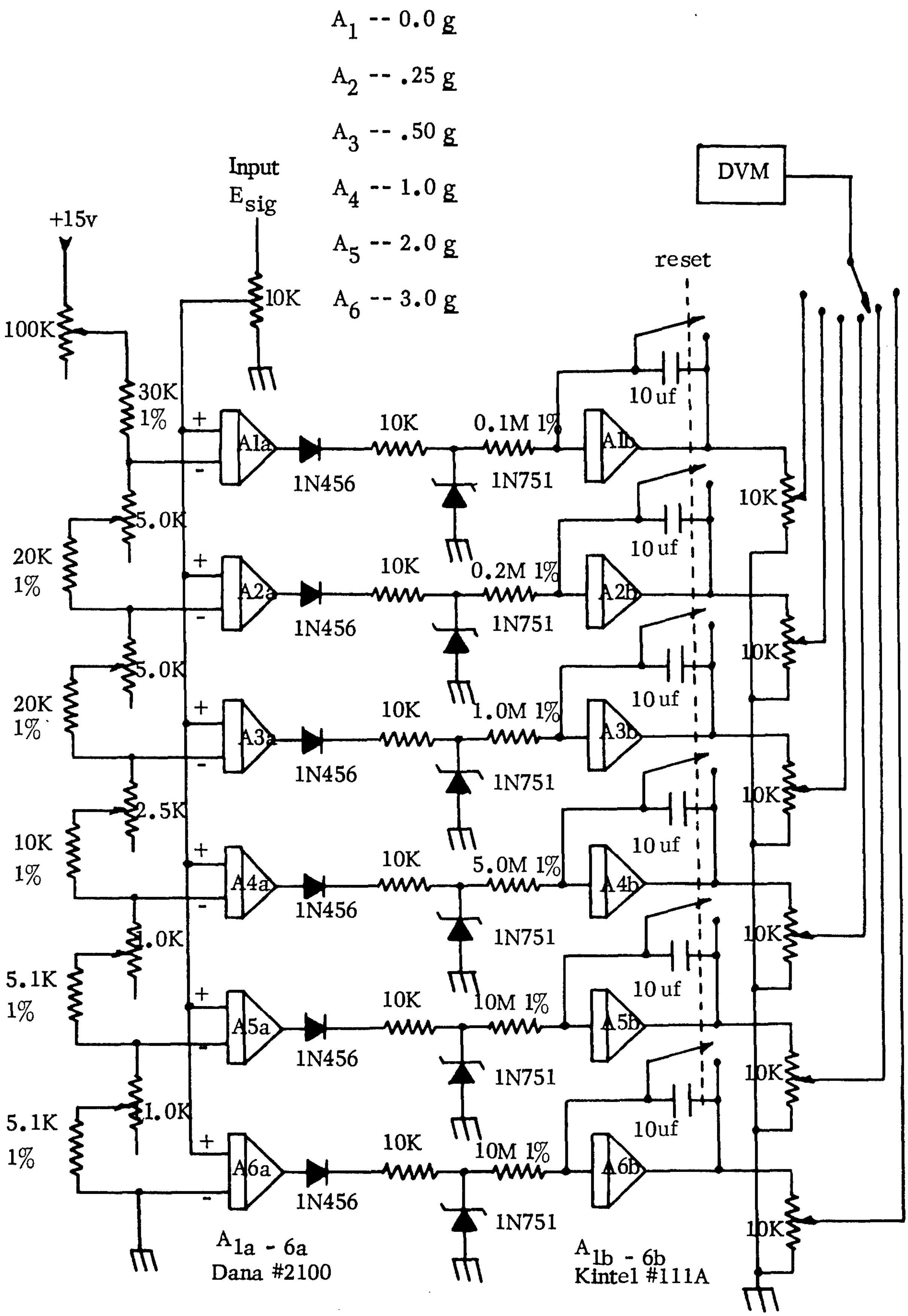

Fig. 2C. REDUCTION CIRCUIT: AMPLITUDE ANALYZER

APPENDIX D

M60 DRIVER VIBRATIONAL-ENVIRONMENT STUDY

MEASUREMENT OF GUNNER POSITION AND TANK-COMMANDER POSITION

Another area of interest was a brief study of the g forces the other crew members experienced. Two of the Ss (Ss 4 and 9) were asked to ride in the commander's and gunner's stations while being driven over the same two cross-country courses. One S rode in the designated position while the other drove. The results of this investigation are given in Tables 1D and 2D. It is interesting to compare the vibration environment in these positions with that of the driver. The major point is that longitudinal g forces are greater in the tank-commander's position than in the driver's position.

This indicates that future work on other positions should include measuring g forces in all three directions, even though this report found the vertical direction was the most significant for the driver.

TABLE 1D

g Environment in Gunner's and Tank Commander's Positions:

RMS g for Cross-Country Course #2

Subject	Test	Position	Vehicle Speed	Vertical Body	Vertical Vehicle	Transverse Body	Transverse Vehicle	Longitudinal Body	Longitudinal Vehicle
4	A	Gunner	13.4	.35	.28	.22	--	.24	--
9	B	Gunner	15.7	.36	.29	.18	--	.25	--
4	C	Tank Commander	12.6	.30	.33	--	--	.34	--
9	D	Tank Commander	14.4	.34	.41	--	--	.42	--

TABLE 2D

g Environment in Gunner's and Tank Commander's Positions: Amplitude Analysis (Percent of time g level exceeded given values) for Cross-Country Course #2

Subject	Test	Position	Vehicle Speed	.25 g	.50 g	1.0 g	2.0 g	3.0g
			Vertical - Body					
4	A	Gunner	13.4	30.1	9.03	1.719	.3284	.0798
9	B	Gunner	15.7	31.2	10.12	2.268	.4240	.1182
4	C	Tank Commander	12.6	27.1	10.11	2.618	.4643	.2287
9	D	Tank Commander	14.4	27.8	8.61	1.383	.0976	.0922
			Vertical - Vehicle					
4	A	Gunner	13.4	26.0	5.96	1.031	.1368	.0238
9	B	Gunner	15.7	27.0	7.13	1.457	.1469	.0173
4	C	Tank Commander	12.6	30.4	8.21	1.637	.3340	.0786
9	D	Tank Commander	14.4	35.0	10.56	2.324	.7235	.2510
			Transverse - Body					
4	A	Gunner	13.4	32.7	1.55	.118	.0237	--
9	B	Gunner	15.7	17.7	2.64	.357	.0285	.0065
4	C	Tank Commander	12.6	--	--	--	--	--
9	D	Tank Commander	14.4	--	--	--	--	--
			Longitudinal - Body					
4	A	Gunner	13.4	19.6	3.74	.844	.1007	.0544
9	B	Gunner	15.7	29.5	5.65	.712	.0212	.0024
4	C	Tank Commander	12.6	34.4	9.31	2.047	.2185	.0352
9	D	Tank Commander	14.4	44.1	14.23	2.940	.3997	.0944

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This study investigated the g environment encountered by M60 tank drivers. It was conducted in two phases. In Phase I, the subjects drove an M60 tank over standard courses at constant speed. This phase examined the repeatability of measuring g loads when different drivers were subjected to the same environment. In Phase II, the subjects drove an M60 tank at maximum speed over two types of cross-country courses. This phase established a correlation between speed and g loads and determined the maximum g load the drivers would accept.

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